

AD-A253 209



MISCELLANEOUS PAPER GL-92-11

2

US Army Corps
of Engineers

STABILITY OF OPEN-GRADED BASES UNDER WHEEL LOADS USING A MODEL TESTING APPROACH

by

Carlos R. Gonzalez

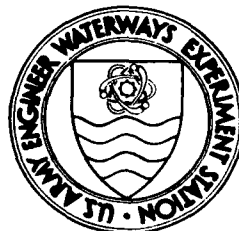
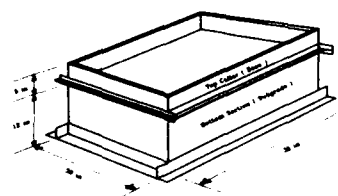
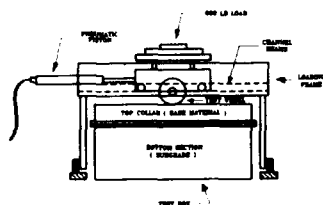
Geotechnical Laboratory

DEPARTMENT OF THE ARMY

Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199



DTIC
ELECTE
JUL 24 1992
S A D



May 1992

Final Report

Approved For Public Release; Distribution Is Unlimited

92-19836



92 7 22 033



Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

**Destroy this report when no longer needed. Do not return
it to the originator.**

**The findings in this report are not to be construed as an official
Department of the Army position unless so designated
by other authorized documents.**

**The contents of this report are not to be used for
advertising, publication, or promotional purposes.
Citation of trade names does not constitute an
official endorsement or approval of the use of
such commercial products.**

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE May 1992		3. REPORT TYPE AND DATES COVERED Final Report
4. TITLE AND SUBTITLE Stability of Open Graded Bases Under Wheel Loads Using a Model Testing Approach			5. FUNDING NUMBERS	
6. AUTHOR(S) Carlos R. Gonzalez				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) USAE Waterways Experiment Station Geotechnical Laboratory 3909 Halls Ferry Road, Vicksburg, MS 39180-6199			8. PERFORMING ORGANIZATION REPORT NUMBER Miscellaneous Paper GL-92-11	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) US Army Corps of Engineers Washington, DC 20314-1000			10. SPONSORING / MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) The stability of open-graded bases of various gradations and types of aggregates were examined when subjected to traffic. A small scale test box was designed and constructed to contain the base materials to be tested. Traffic was applied with a tire load directly on top of the bases. Rut depths at the deepest point of the wheel path were taken and used as a measurement of the stability of the material. Six different gradations of two types of materials were tested and compared with the performance of the US Army Corps of Engineers standard crushed stone base coarse gradation. Recommendations are given as to the type of material and gradation that would be most stable under direct traffic.				
14. SUBJECT TERMS Base gradation Open-graded bases Rut depth Crushed stone Round gravel Wheel passes			15. NUMBER OF PAGES 44	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT	

PREFACE

The investigation reported herein was sponsored by the Office, Chief of Engineers (OCE), under the work effort "Life Cycle Cost for Drainage Structures (Pipe)," of the Facilities Investigation and Studies Program. The OCE Technical Monitor was Mr. M. K. Lee.

This study was conducted at the US Army Engineer Waterways Experiment Station (WES) from June 1987 through December 1987 by the Pavement System Division (PSD) of the Geotechnical Laboratory (GL). This report was written by Mr. Carlos R. Gonzalez under the supervision of Dr. George M. Hammitt II, Chief, PSD; and D. M. Ladd, Chief, Criteria Development Unit, PSD. The work was performed under the general supervision of Dr. W. F. Marcuson III, Director, GL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander and Deputy Director was COL Leonard G. Hassell, EN.

Accession For	
NTIS CRA&I	<input checked="checked" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution /	
Availability Codes	
Dist	Avail and/or Special
A-1	

CONTENTS

	<u>Page</u>
PREFACE.....	1
CONVERSION FACTORS, NON-SI TO SI (METRIC)	
UNITS OF MEASUREMENT.....	3
PART I: INTRODUCTION.....	4
Purpose.....	4
Approach.....	5
PART II: MATERIALS AND EQUIPMENT.....	7
PART III: TESTING PROCEDURE.....	11
PART IV: ANALYSIS OF TRAFFIC RESULTS.....	13
PART V: CONCLUSIONS AND RECOMMENDATION.....	18
Conclusions.....	18
Recommendations.....	18
TABLES 1-3	
FIGURES 1-6	
PHOTOS 1-37	

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI
(metric) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
feet	0.3048	metres
inches	2.54	centimetres
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals

STABILITY OF OPEN-GRADED BASES UNDER WHEEL
LOADS USING A MODEL TESTING APPROACH

PART I: INTRODUCTION

1. The rising concern within the Corps of Engineers (CE) in improving the drainage of pavements has brought the idea of using open-graded bases. Open-graded bases are layers of granular aggregates sufficiently permeable to allow rapid drainage of pavement systems and strong enough to sustain the expected traffic loads. The ability of these layers to sustain repetitive wheel loads within a reasonable deflection range is called stability. The stability, which is determined by measuring the rut depths on the wheel path, depends on the material that the layers are made of, the magnitude of the load, and the number of applications (passes) of that load. For aggregate layers to achieve adequate strength, the interaction between particles must be such that maximum shear resistance is developed. This usually happens when the material is densely compacted by adding a certain amount of fines, thereby reducing the void spaces within the layer. Consequently, because the drainage of an aggregate layer depends upon the voids available to drain the water, the addition of fines will reduce its permeability. The drainage condition is satisfied if larger aggregates are used. Therefore, a compromise between strength and permeability is necessary in the selection of the appropriate gradation for an open-graded layer. Because of these requirements, open-graded bases will probably have gradations with slightly less strength than the densely compacted bases. This has raised the question of how stable are these layers under typical construction operations where the traffic is applied directly on the open-graded bases.

Purpose

2. The purpose of this study was to examine the stability of different gradations and types of aggregates when subjected to traffic.

Approach

3. To study the stability of open-graded bases, a small-scale test box, with dimensions as shown in Figure 1, was designed and constructed. This box basically consisted of two sections--a bottom section containing a 12-in.* layer of sandy gravel material which acted as a subbase and a 5-in. top section (collar) that contained the open-graded base course material to be trafficked. To determine the open-graded thickness of 5 in., the CE flexible pavement design criteria was used for a tire load of 600 lb inflated to its maximum allowable pressure of 32 psi (Grau 1984**). A synthetic filter fabric was installed between these two layers to avoid the migration of fines from the subgrade to the base. The loaded wheel was driven back and forth by a pneumatic piston to apply repeated traffic directly over the base course. Rut depths at the deepest point on the wheel path were taken and used as a measurement of the stability of the material. Readings were also taken at various pass levels until the deformations ceased to increase.

4. The stability of the different materials under direct traffic loads was measured relative to a reference material. The reference material selected for this investigation was the CE standard crushed base stone coarse gradation. Several different gradations of crushed stone and river-run gravel were tested and their performance compared and evaluated against the reference material by measuring rut depths during traffic. Plots of the rut depths against the number of repetitions are presented for the different gradations and materials tested.

* A table of factors for converting non-SI to SI (metric) units of measurement is presented on page 3.

** Grau, Richard H. 1984. "Engineering Criteria for Use of Geotextile Fabrics in Pavement and Railroad Construction," Technical Report GL-84-6, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

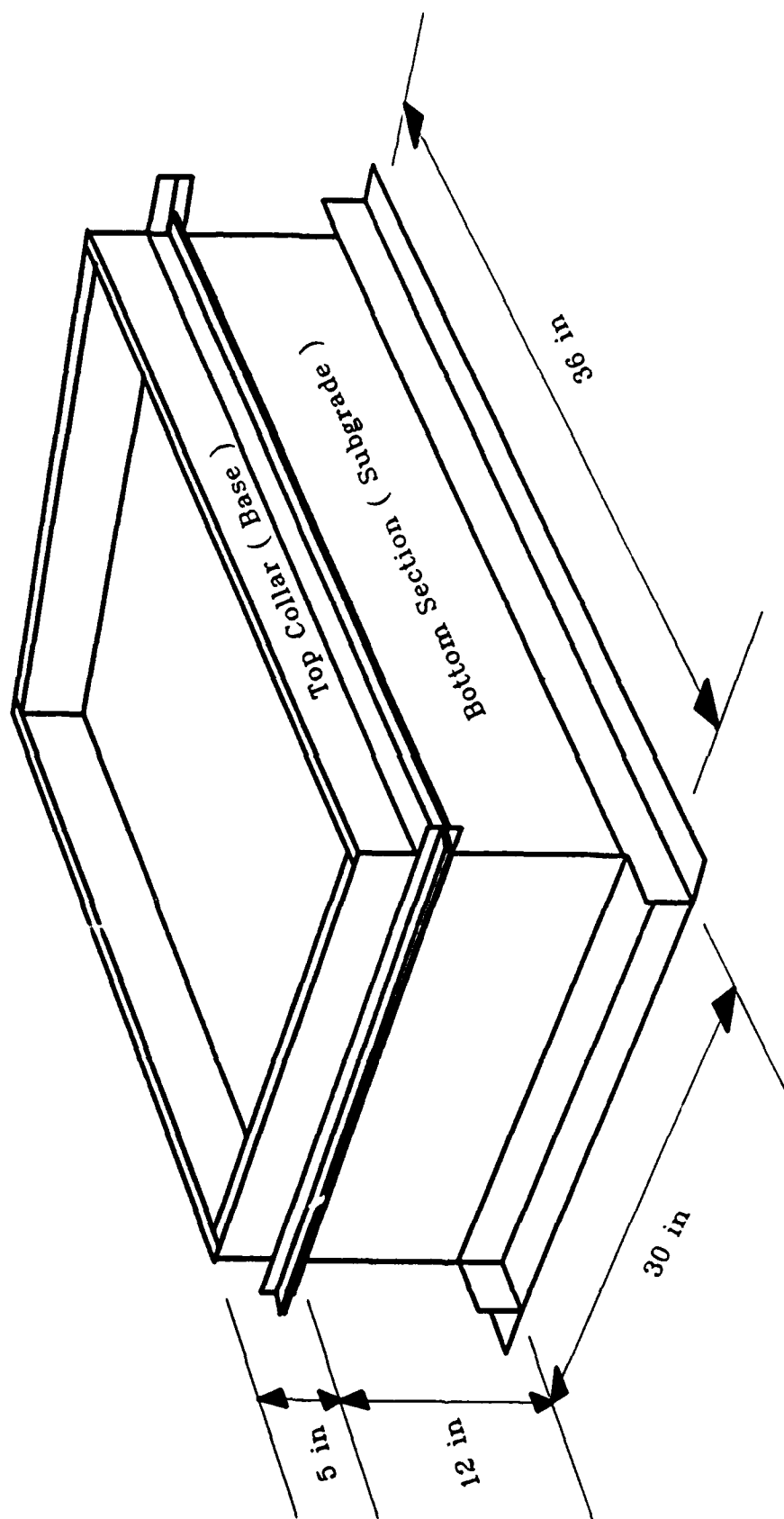


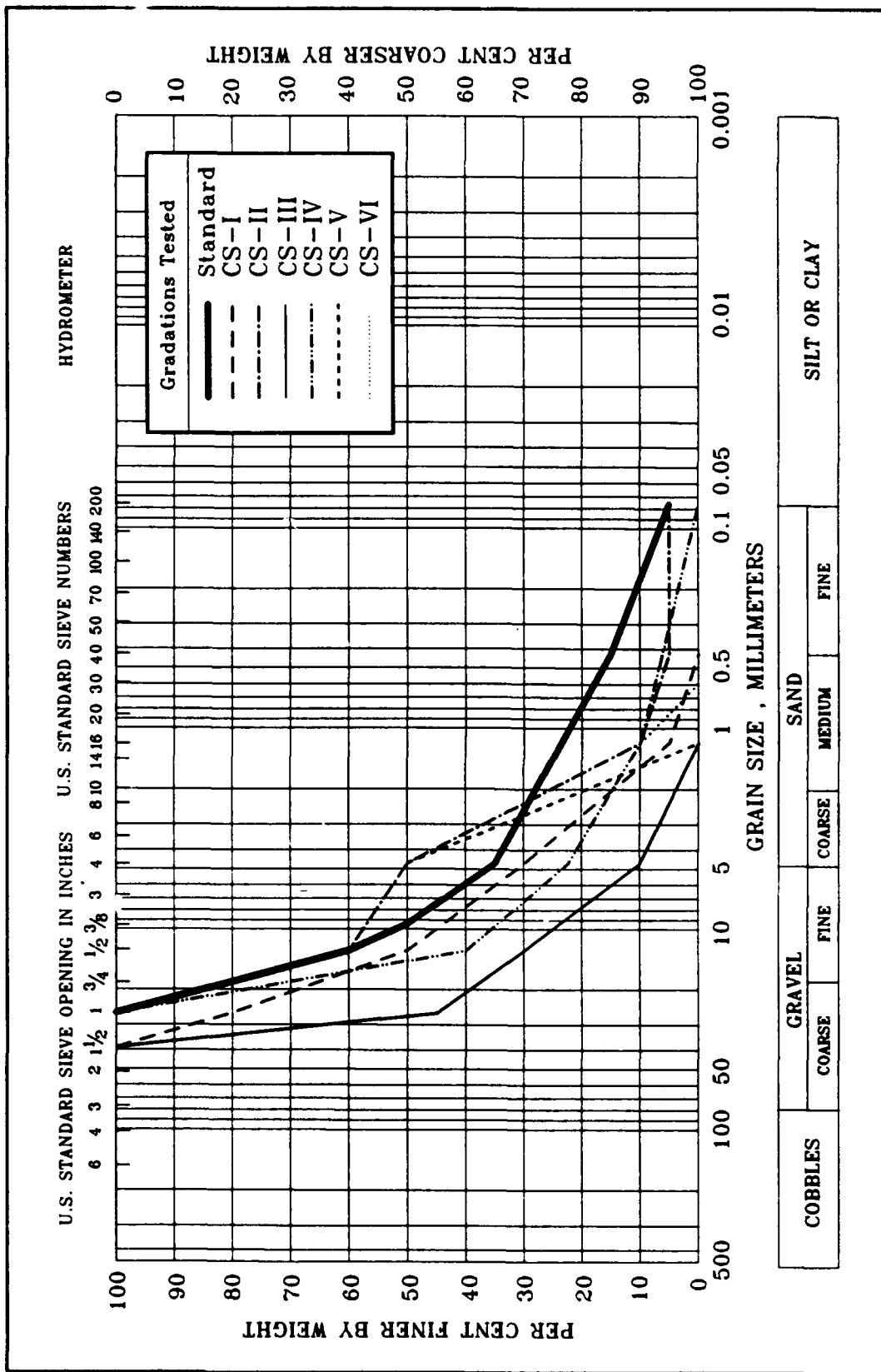
Figure 1. Small-scale test box

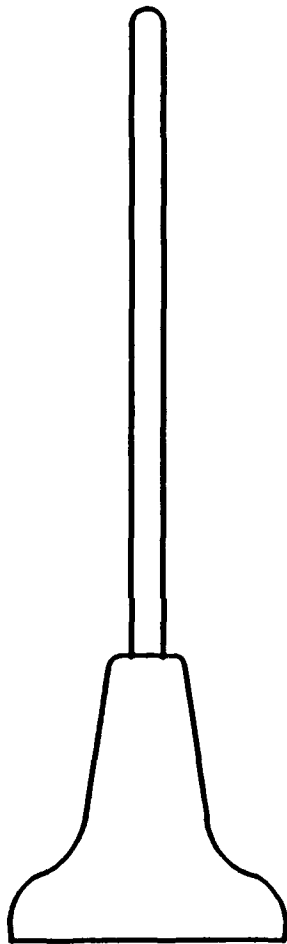
PART II: MATERIALS AND EQUIPMENT

5. Six different gradations and the standard CE base course gradation were tested in the first test series. Table 1 shows the aggregate size distributions and Figure 2 illustrates their corresponding gradation curves. The openness of the materials was controlled by reducing the amount of fines in the mixture and by permitting the use of larger aggregates. Crushed limestone was first utilized as the basic base course material for the first test series whose objective was to determine the gradation most suitable to be used as an open-graded base. A second test series was performed on the standard gradation and on the more stable gradation resulting from the first test series, using river-rounded aggregates to evaluate the effect of rounded materials on the performance of open-graded bases.

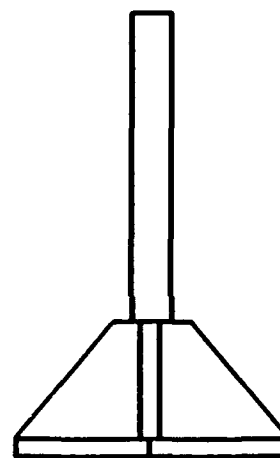
6. The preparation of each base course consisted of weighing the different sizes of aggregates according to their specific gradations, blending them together to get a uniform mixture, filling the box with the mixture, and compacting it. Due to the small size of the box, the blending and compaction procedures could be achieved manually. Two hand tampers, weighing 20 lb each were used to densify the subbase and base courses. Figure 3 shows a diagram of the hand tampers used during the tests.

7. Figure 4 illustrates in more detail the small-scale test box and the loading system used. The box consisted of a 12 in. high fixed bottom section designed to contain the subbase material and a 5 in. high top collar where the open-graded material is placed. A moving frame holding the small tire and the loading plate was used to apply the loading. This outer frame has two channel beams where the wheel and the loading plate roll over. The test wheel can move freely up and down if necessary, but the loading plate assembly will always slide over the channel beams. The horizontal pneumatic piston drives the test tire back and forth directly over the base material at a speed of approximate 1 ft/sec.





6-1/4" diameter



6" X 6"

Figure 3. Twenty-pound hand tampers

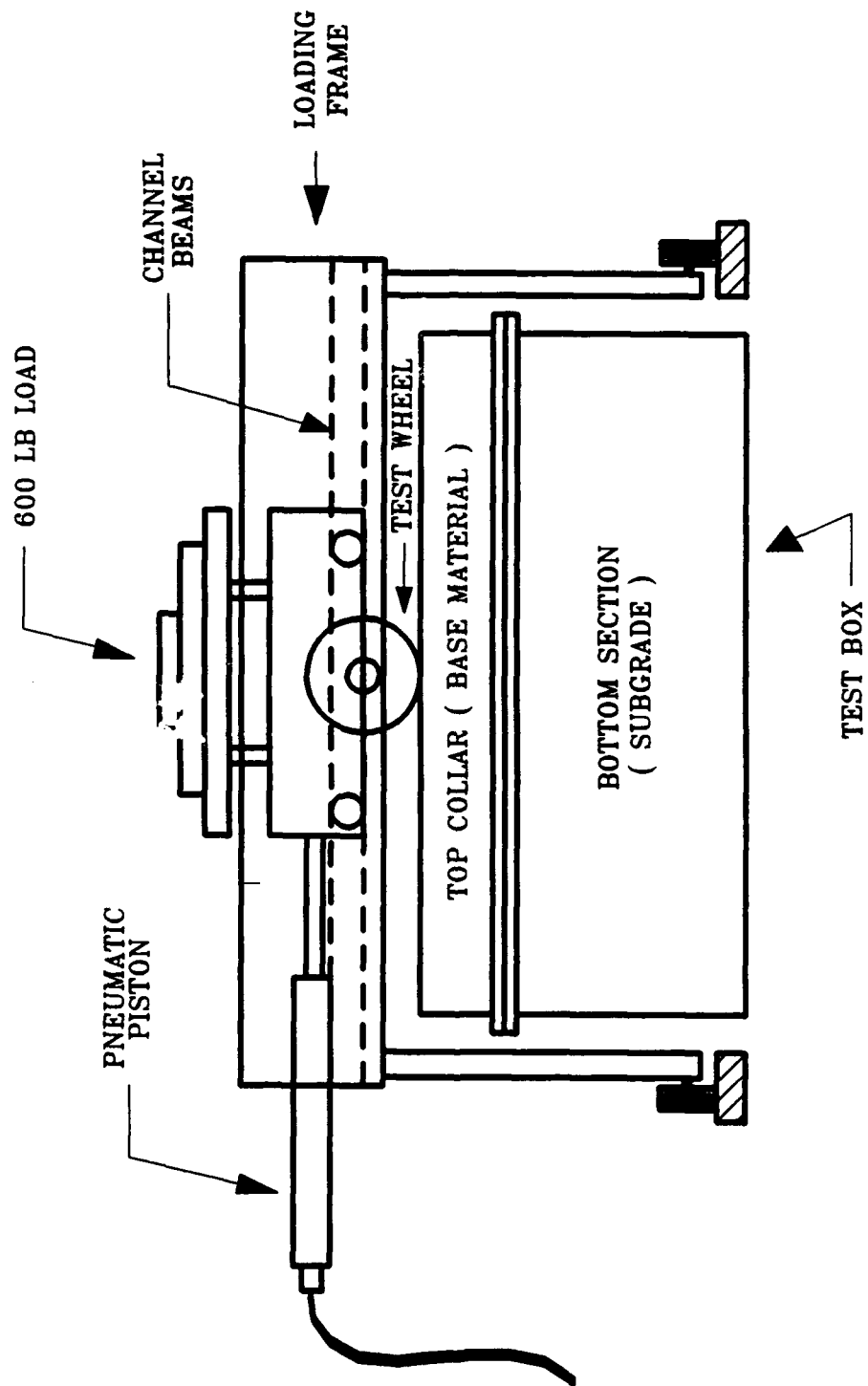


Figure 4. Loading system used

PART III: TESTING PROCEDURE

8. This section outlines the testing procedure followed throughout the tests.

- a. The first step was to place and to compact the subbase material in the bottom section of the test box. Approximately, 1,080 lb of sandy gravel was mixed with 5 percent of water and then hand blended to obtain a uniform mix. The subbase material was placed and compacted using hand tampers (Photo 1). The total weight of the material inside the bottom section was determined by weighing the soil when placed in the box. Care was taken to fill all the areas of the box and not to segregate the material. The final surface was then leveled and material samples were taken to determine its water content. A wet density of 130.7 pcf was achieved at a measured water content of 4.4 percent. The total weight of material was 980 lb. Photo 2 shows the texture of the final subbase surface.
- b. The filter fabric was then placed on top of the subgrade to prevent migration of fines between the subbase and the base. Photo 3 shows the filter fabric and the top collar in place.
- c. The various sizes of aggregate used in blending the open-graded base were then weighed before mixing (Photo 4). Hand blending was then performed on the dry material to get a uniform mixture, followed by the addition of 5 percent water (Photos 5-9). The material was re-blended, placed in the top collar, and compacted. Again, the material was leveled, weighed, and samples taken to determine its water content. Photos 10-15 show the mixing procedure, a typical look of the final mixture, the placement of the material in the box, and the hand compaction. Photo 16 shows the weighing of the 600-lb load.
- d. The tire pressure was set to 32-psi pressure. The loading frame supporting the test wheel was placed directly on top of the open-graded base material (Photo 17). Finally, the 600-lb load was placed on top of the supporting frame. Photo 18 shows the box assembly ready to be tested.
- e. At this point the open-graded base was ready for traffic application. A horizontal pneumatic piston was activated to drive the loading frame back and forth along a straight path. Rut depth measurements were taken at the deepest point on the wheel path at various pass levels (i.e. No. 1, 2, 4, 6, 10, 16, 20, 40, 50, etc.). The load applications were continued until the rut depths did not change significantly or until the rut depths became so deep that the loading frame dragged on the surface of the base. Photo 19 shows the pneumatic piston driving the loading frame back and forth. Photo 20 shows the test box during testing.

- f. Finally, to obtain the relative permeability of the different gradations, a simple test was performed directly on top of the base. The test consisted of measuring the time it required for a 2-1/8-in.-diam column of water to fall 5 in. while draining into the base course. Photos 21 and 22 show the PVC pipe utilized for this purpose. It consisted of a pipe with a plastic base and a hole in its side connected to a water hose. Clay was used to seal the contact between the plastic base and the surface of the base course so that the water was forced to move downward through the base. A weight was placed on top of the pipe to keep it from moving during the test. After the pipe was filled close to its top, the time required for the water to fall freely 5 in. was recorded using a stop watch. The test was performed three times and the average used as the measurement of the permeability. Photos 23-37 show the texture of each of the gradations tested before and during traffic.

PART IV: ANALYSIS OF TRAFFIC RESULTS

9. Table 2 contains the rut depth measurements resulting from the applied traffic on the different gradations of crushed stone tested. Figure 5 illustrates graphically their relative performance as the number of passes increased. Two patterns of performance can be easily noted from the shape of the curves. The first pattern, developed from tests on materials CS-I, CS-III, and CS-IIIA, showed the rut depth increasing rapidly as traffic increased and then stabilized at about 20 passes. The second pattern, developed by tests on the remaining gradations, showed some kind of material densification and aggregate rearrangement before following a stable behavior. Again, this occurred at about 20 passes. It is important to notice that rutting was larger for the first pattern of performance than for the second pattern.

10. In these tests the CS-III gradation represented the most open-graded base and the standard CE gradation represented the least open. This is illustrated in Figure 2, where CS-III is the gradation with the least percent of fines and the larger aggregates, and the standard CE gradation has a more uniform aggregate size distribution and a the higher percent of fines. As expected, these two gradations also became the lower and upper boundaries in terms of rutting stability. The CS-III gradation exhibited rapid rutting after a small number of passes. After 4 passes the rut depth already exceeded 1 in., increasing from that point to 2.25 in. The CS-III gradation had the same aggregate gradation as the CS-IIIA, but the behavior of the former was greatly affected by material segregation that occurred during the filling of the box. The CS-III showed significantly more rutting than the CS-IIIA, which was carefully placed and compacted. For example, at 100 passes the CS-IIIA had a 1.31-in. rut depth while the CS-III had 2.25-in. rut. This represents approximately 70 percent increase in rutting and, consequently, a 70 percent reduction in stability due to construction errors. This points out the importance of proper material quality control during the placement of any open-graded base.

11. The CS-II material was similar to the standard CE material but contained fewer fines (see Figure 2). As expected, it exhibited a very good performance under traffic having almost the same behavior as the standard

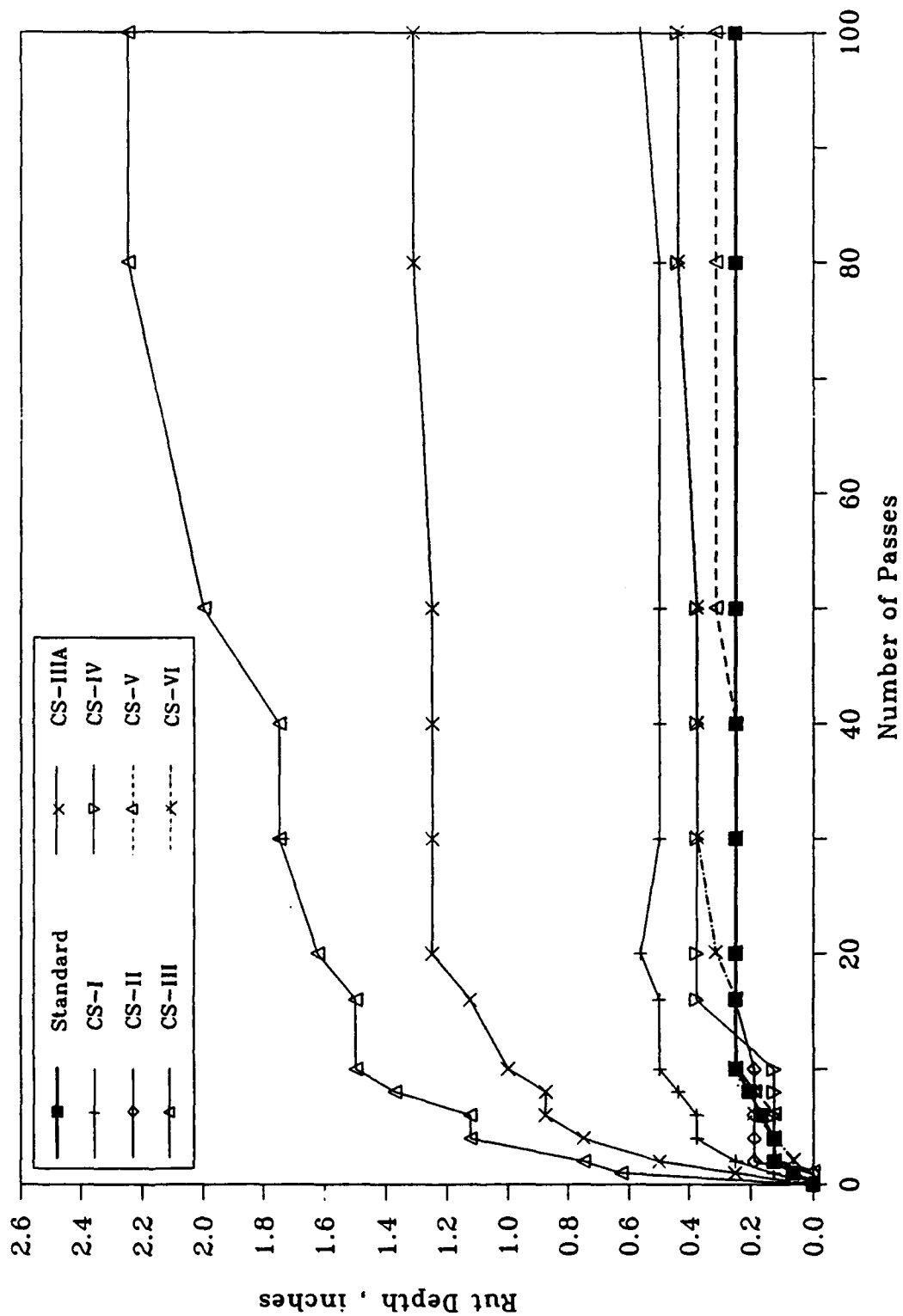


Figure 5. Relative performance

gradation. This reduction in fines permitted the CS-II gradation to drain the water faster. It also demonstrated that decreasing the amount of fines in the mixture will not necessarily decrease the stability of the base. Based on these results, the fines for the CS-II were again decreased to make it more open and to evaluate its behavior. The percent of material passing sieve No. 30 and sieve No. 16 were set to zero to obtain the CS-V and CS-VI gradations, respectively. The results clearly demonstrated that the reduction of fines in the mixture only slightly reduced the capacity of the material to sustain traffic (Figure 5). Surprisingly, both resulted in rut depths only slightly higher than the standard base, not exceeding five-sixteenths inch for the CS-V and seven-sixteenths inch for the CS-VI.

12. The gradation of CS-I was similar to the CS-III gradation curve but it is considerably less open. This gradation resulted in a fairly good stability, with a performance between the CS-III and the CS-VI, having rut depths slightly more than one-half inch, but not exceeding five-eighths inch. On the other hand, the gradation represented by CS-IV, which followed the shape of the standard gradation curve, showed a stability as good as the CS-V and CS-VI, but again, this gradation contains a much greater amount of fines than the CS-V or CS-VI. The amount of fines in the CS-IV gradation makes it less permeable and, therefore, less suitable as an open-graded base. CS-V was judged to be the most stable of the nonstandard gradation bases.

13. The results of two tests performed on the CE standard and the CS-V gradations, utilizing in this case rounded aggregates instead of crushed stone, are presented in Table 2 and Figure 6. The rut depths of the standard gradations indicate that its stability was greatly reduced when compared with the standard crushed stone gradation. In this case the rut depth increased up to eleven-sixteenths inch compared with only one-fourth inch for the crushed stone. In fact, the resulting rut depths were greater than all of the more open crushed graded bases tested, except the CS-III. This is an indication of the poor stability that can occur in the field during the placement of bases with rounded aggregates. This fact was confirmed with the results from the CS-V gradation. In this case, the deformations became so large that the test had to be stopped after only a few passes because the equipment was dragging on top of the base. After only 8 passes the rut depth increased to 2-11/16 in. As these tests demonstrated, rounded materials do not provide

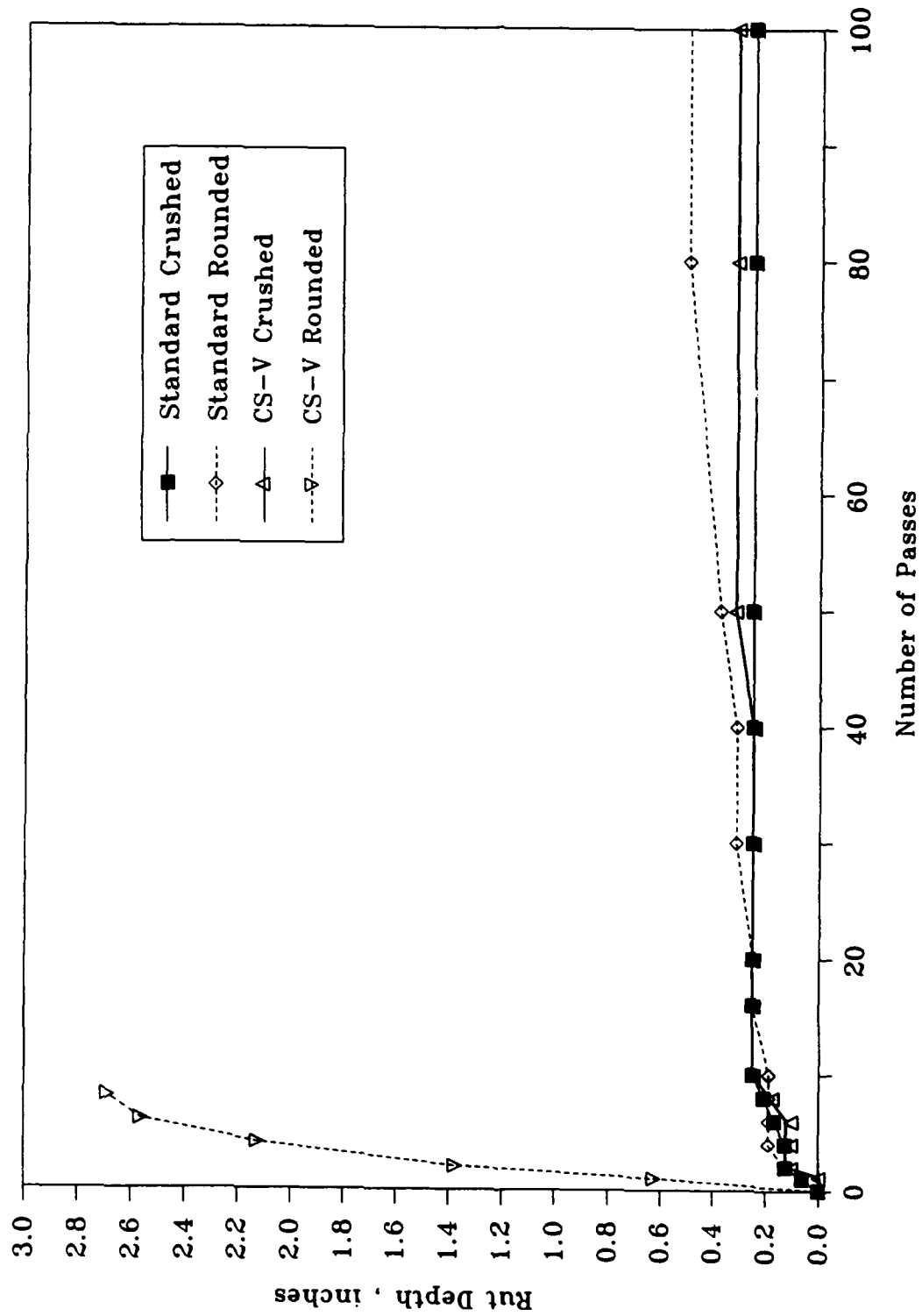


Figure 6. Test results, crushed and rounded aggregate

good particle interlock, resulting in slip between aggregates and reduction of stability under traffic.

14. Table 3 contains the results of the permeability tests. These results show that water percolates as much as 12 times faster in the open gradations CS-V and CS-VI than for the standard base. The standard material drained the water in about 23.5 sec while the CS-V and CS-VI drained it in about 2.0 sec. An interesting point was that the CS-II took more than twice the drainage time of the CS-V or CS-VI, indicating that the reduction of fines in the CS-II to produce the CS-V or CS-VI had the expected effect on permeability.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

15. Based on the results of the tests conducted, the following conclusions are presented:

- a. Gradations similar to the CS-V or CS-VI were found to be suitable for use as open-graded bases. These gradations provided an acceptable permeability without sacrificing strength or stability under direct traffic loads.
- b. The performance of the open-graded base made up of rounded aggregates (CS-V) resulted in a dramatic reduction in stability. Even the standard gradation base constructed from rounded aggregates did not show an acceptable stability under traffic. Therefore, rounded aggregates should not be used for open-graded bases.
- c. Segregation of the open-graded bases during placement could be a cause for considerable loss in stability. Care should be taken to control the quality of open-graded base.
- d. The permeability, as determined in these tests, can be at least 12 times greater for open-graded bases than for well graded bases.

Recommendations

15. Based on this study, the following recommendations are suggested:

- a. Determine the stability and permeability of asphalt or cement stabilized open-graded bases through further research.
- b. Compliment the data and establish the best gradation to be used as an open-graded base through field testing of open-graded bases constructed with gradations similar to those investigated in this study.
- c. Conduct a research effort to develop a method for measuring the field permeability of pavement bases.

Table 1
Base Course Gradation Tested

<u>Sieve Size</u>	<u>Percent Finer by Weight</u>						
	<u>Standard</u>	<u>CS-I</u>	<u>CS-II</u>	<u>CS-III</u>	<u>CS-IV</u>	<u>CS-V</u>	<u>CS-VI</u>
1-1/2 in.		100		100			
1 in.	100	80	100	45	100	100	100
1/2 in.	60	50	60	30	40	60	60
3/8 in.	50						
No. 4	35	30	50	10	22	50	50
No. 16		5	10	0	10	10	0
No. 30						0	
No. 40	15	0	5		6		
No. 100							
No. 200	5		5		0		

Table 2
Test Results

Number of Passes	Rut Depth Measurements, in.							
	<u>Standard</u>	<u>Crushed Aggregates</u>						<u>Rounded Aggregates</u>
		<u>CS-I</u>	<u>CS-II</u>	<u>CS-III</u>	<u>CS-IIIA</u>	<u>CS-IV</u>	<u>CS-V</u>	
1	0.063	0.125	0.000	0.625	0.250	0.063	0.063	0.625
2	0.125	0.250	0.188	0.750	0.500	0.125	0.063	1.375
4	0.125	0.375	0.188	1.125	0.750	0.125	0.125	2.125
6		0.375	0.188	1.125	0.875	0.125	0.125	2.563
8		0.438	0.188	1.375	0.875	0.125	0.188	2.688
10	0.250	0.500	0.188	1.500	1.000	0.125	0.250	0.188
16		0.500	0.250	1.500	1.125	0.375	0.250	0.250
20		0.562	0.250	1.625	1.250	0.375	0.313	0.250
30	0.250	0.500	0.250	1.750	1.250	0.375	0.375	0.313
40		0.500	0.250	1.750	1.250	0.375	0.375	0.313
50	0.250	0.500	0.250	2.000	1.250	0.375	0.375	0.375
80		0.500	0.250	2.250	1.312	0.438	0.438	0.500
100	0.250	0.562	0.250	2.250	1.312	0.438	0.438	0.500
200	0.250	0.625				0.500	0.438	0.688
300							0.688	
400	0.250							
500	0.250							
600	0.250							
700	0.250							
800	0.250							
900	0.250							
1000	0.250							

Table 3
Permeability Results for the Gradations Tested

<u>Gradation</u>	<u>Time sec*</u>
Standard	23.5
CS-I	1.0
CS-II	5.0
CS-III	0.0**
CS-IIIA	0.0**
CS-IV	9.0
CS-V	2.9
CS-VI	1.9

* Average of the time for water to fall freely 5 in. in a 2-1/8 in. diam tube.

** Too fast to measure.

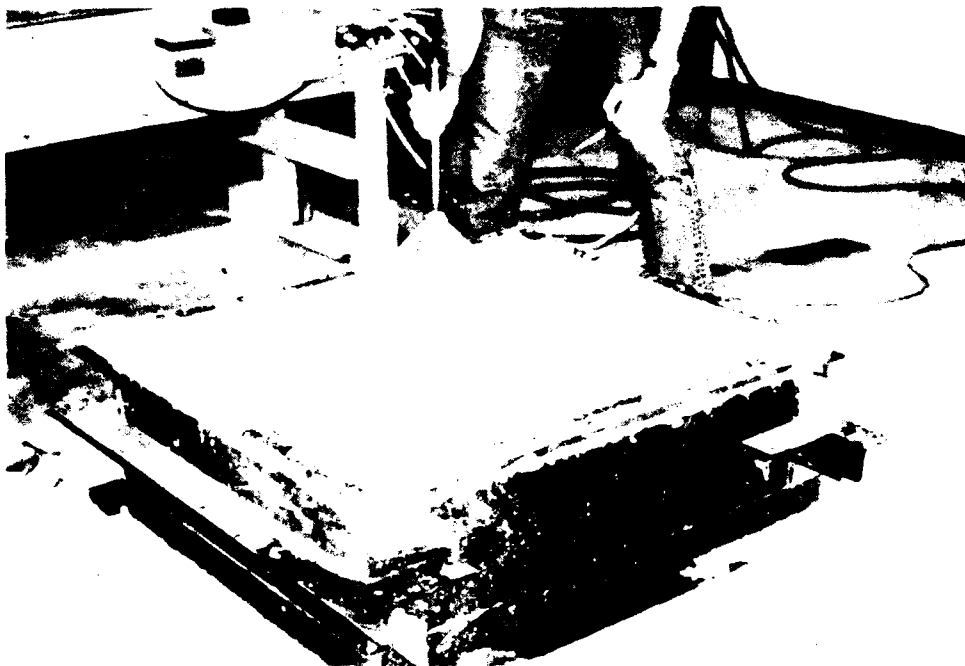


Photo 1. Compaction of subgrade material

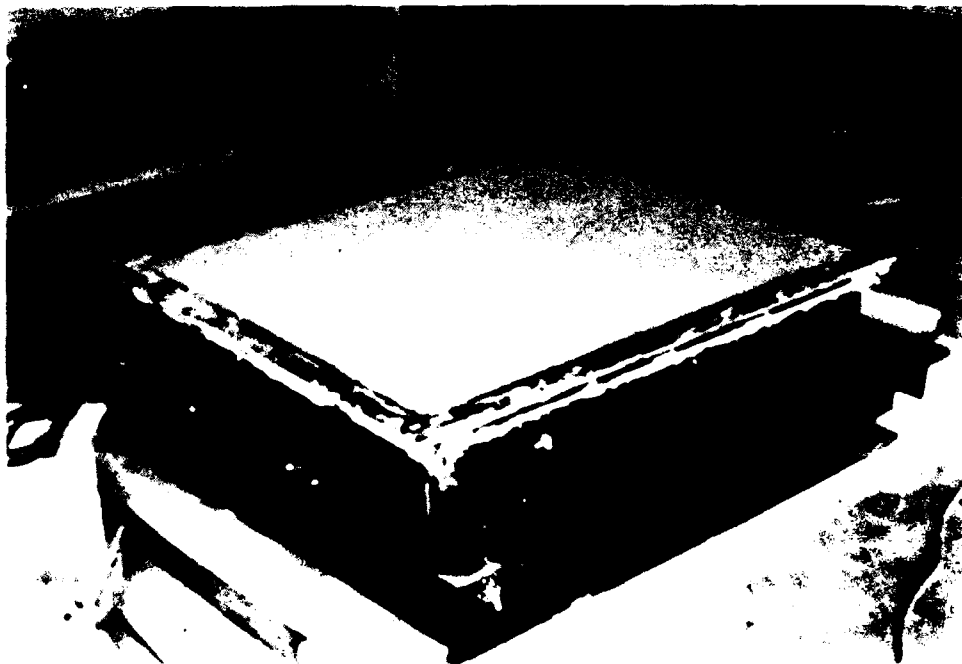


Photo 2. Finished subgrade surface

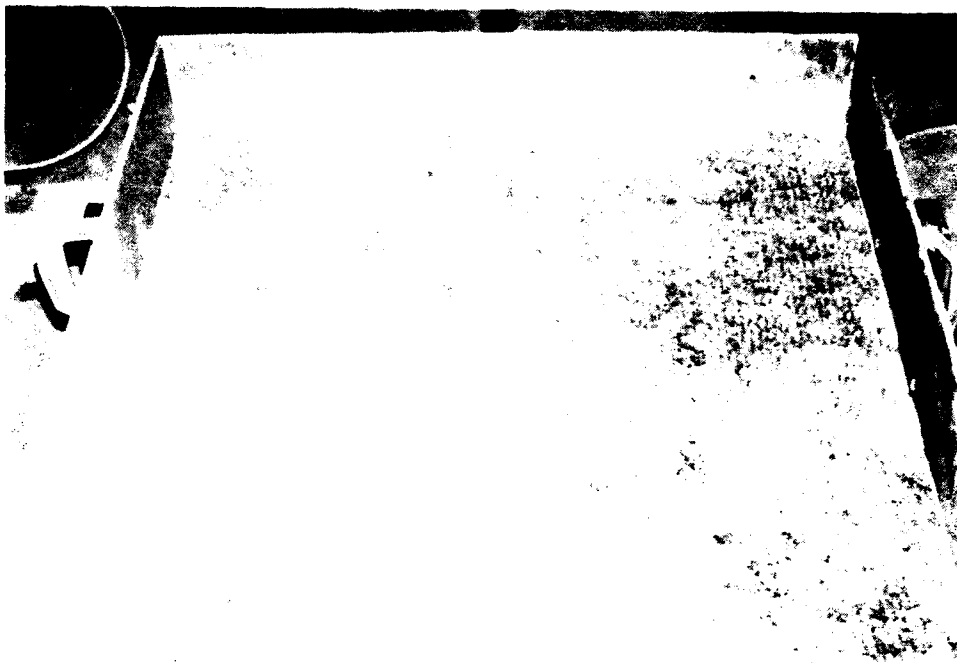


Photo 3. Filter fabric in place



Photo 4. Weighing aggregates according
to gradations



Photo 5. Hand mixing of the coarser aggregates



Photo 6. Addition of finer aggregates



Photo 7. Re-blending of the mix



Photo 8. Weighing water to be added



Photo 9. Addition of water to the mix



Photo 10. Re-blending the final mix

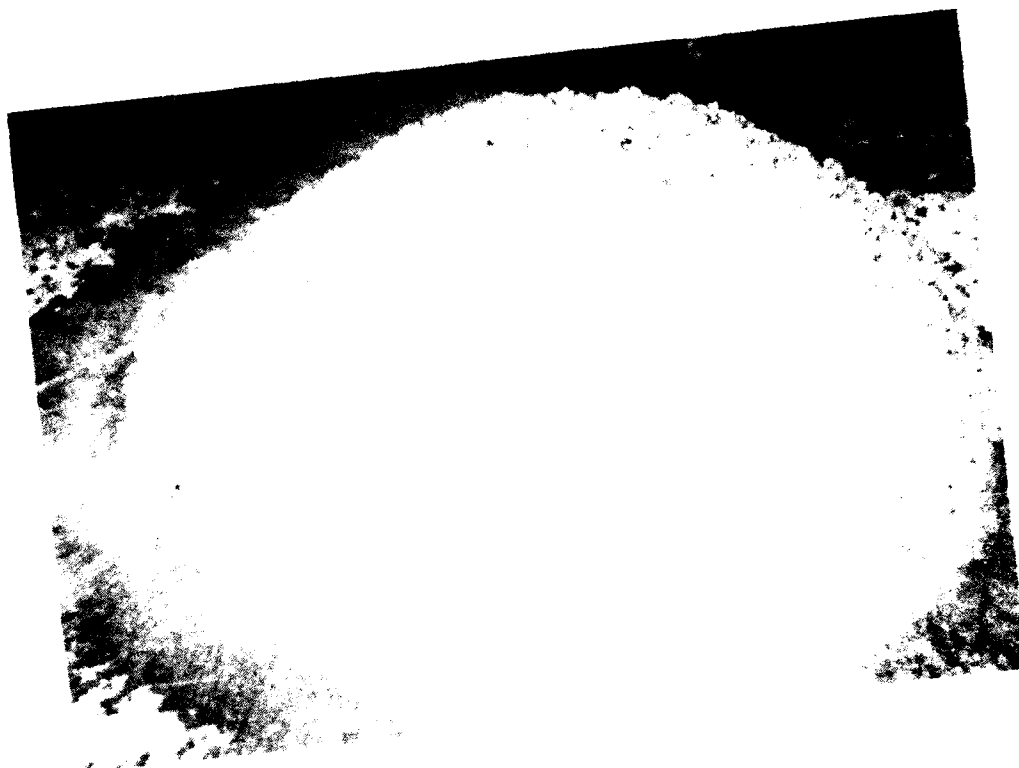


Photo 11. Finished mix

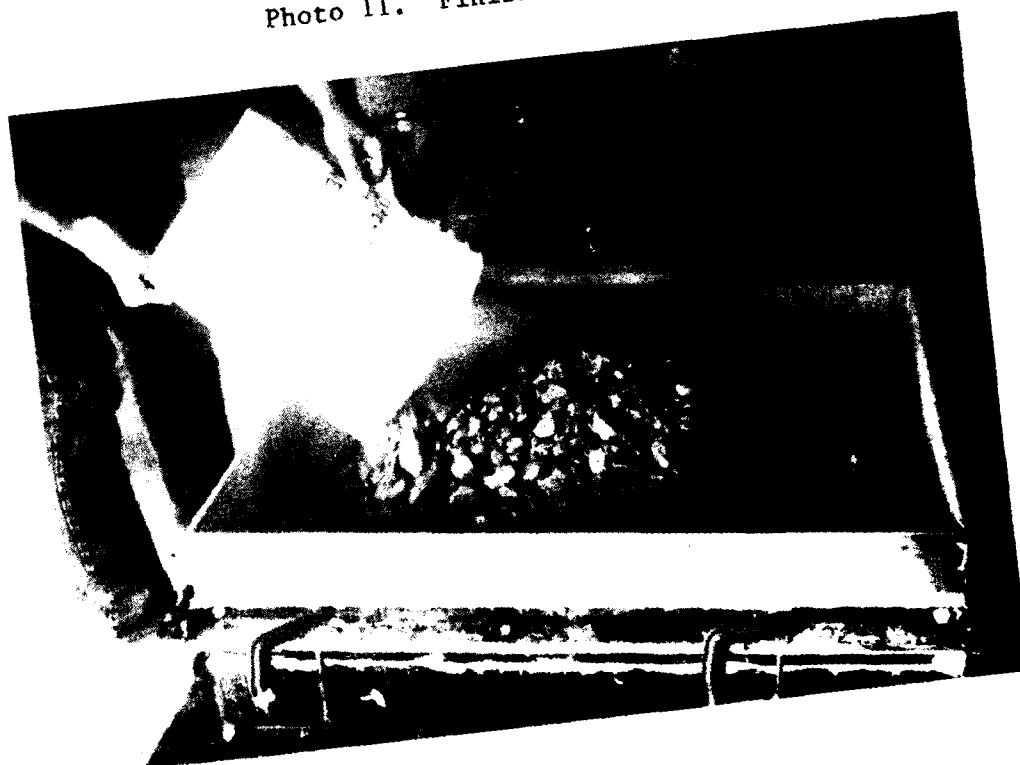


Photo 12. Placement of material in the box

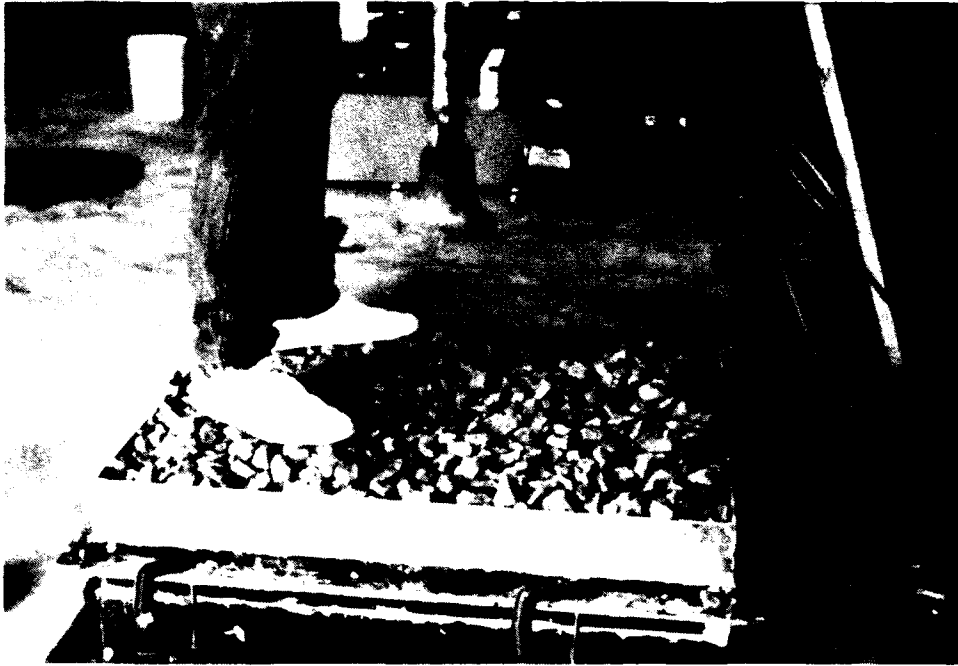


Photo 13. Compaction of the base material

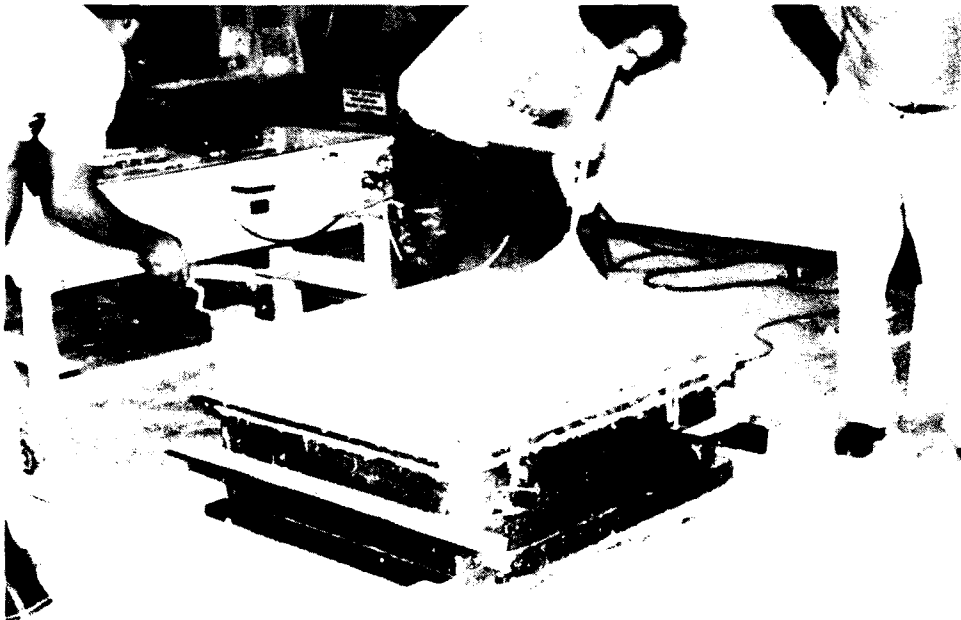


Photo 14. Compaction and edging the base material

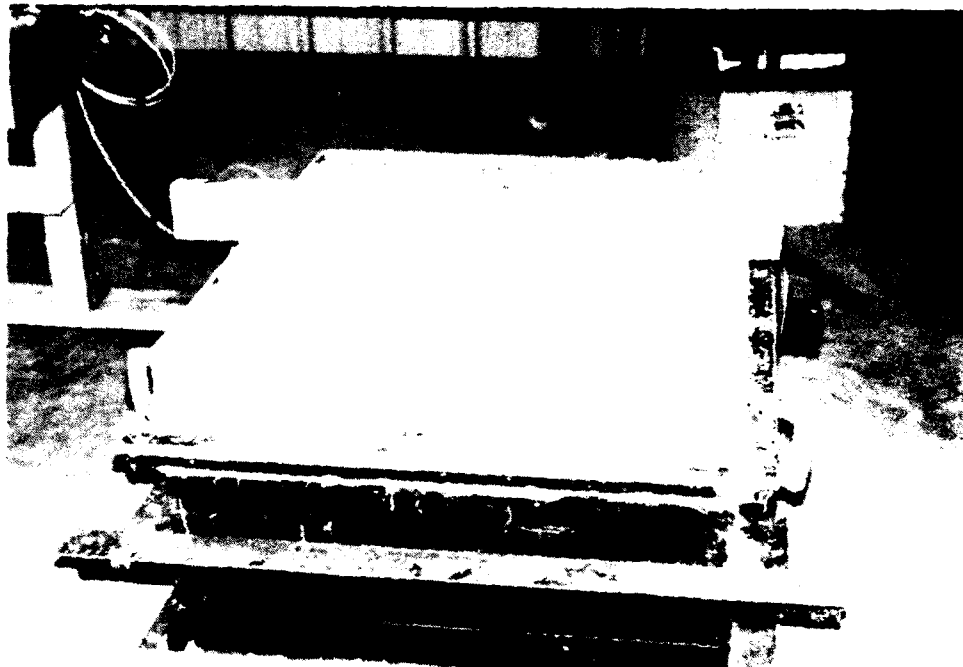


Photo 15. Flattening of the base surface

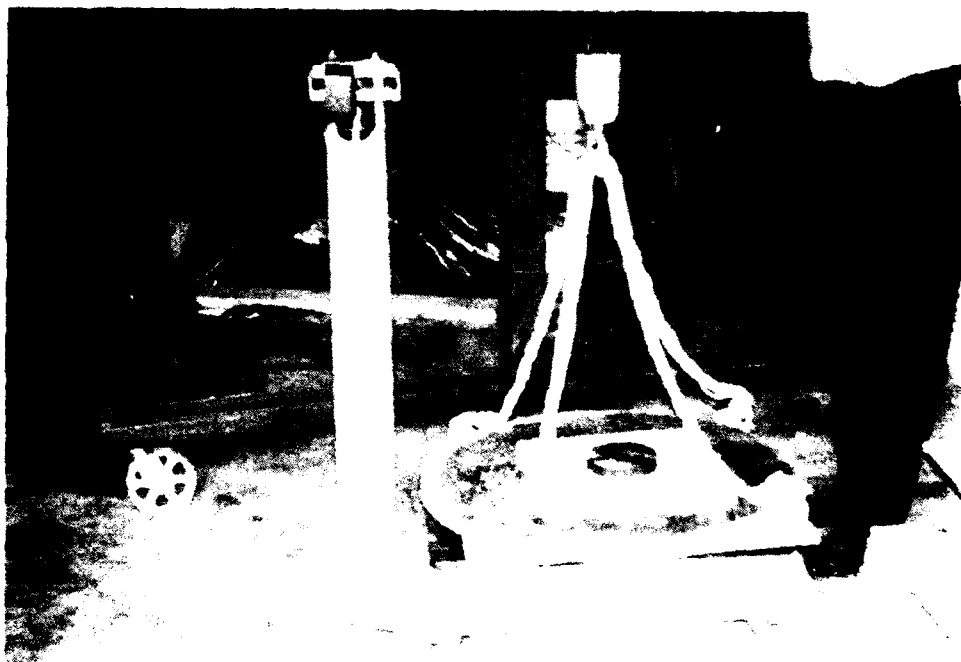


Photo 16. Weighing the 600-lb load

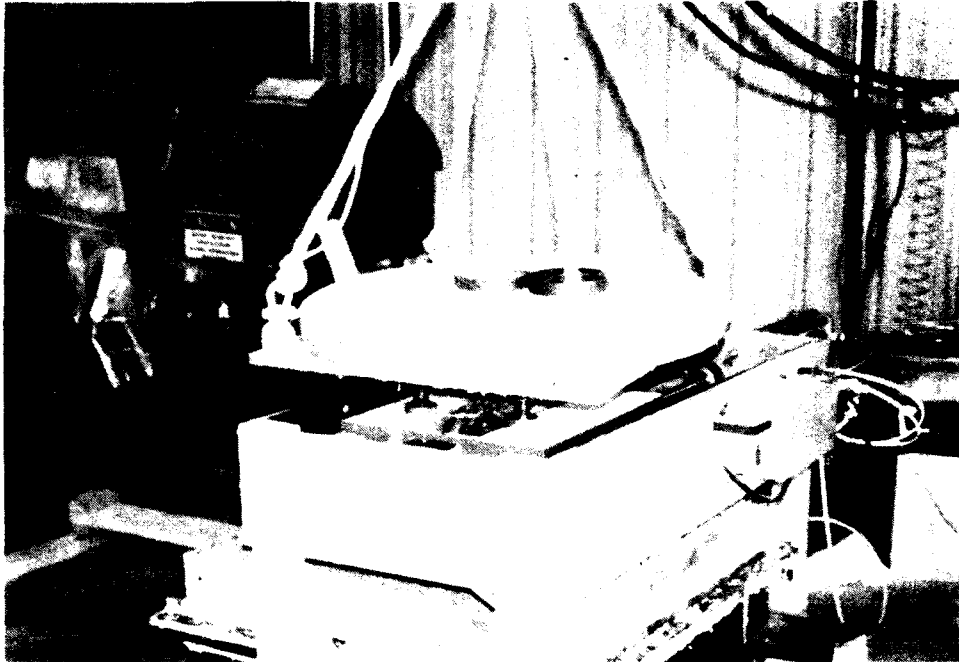


Photo 17. Placement of the load on the loading frame

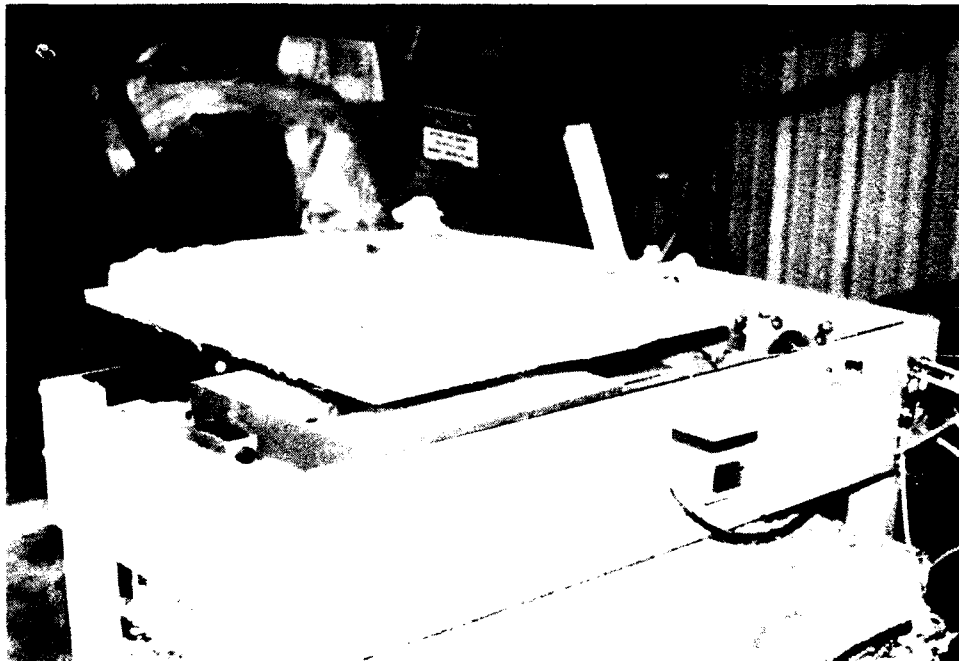


Photo 18. Load placed and ready to be tested

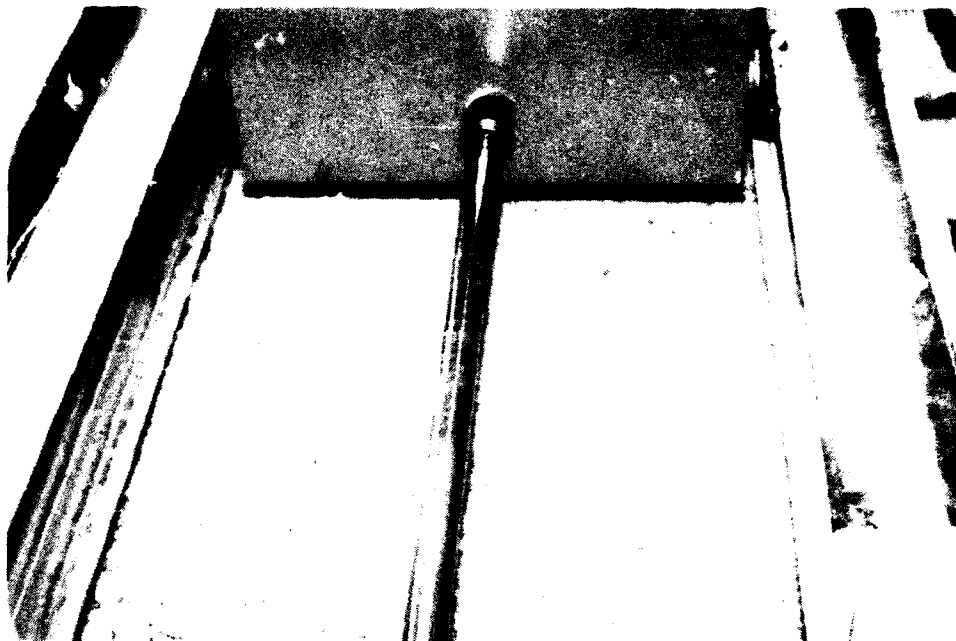


Photo 19. Inside look at the loading frame

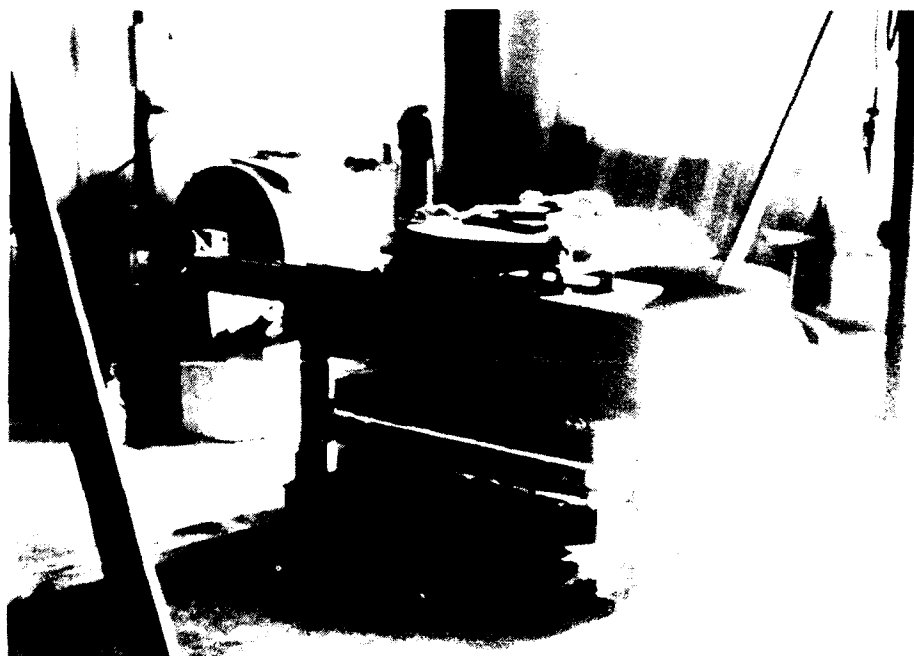


Photo 20. Small-scale box assembly during testing

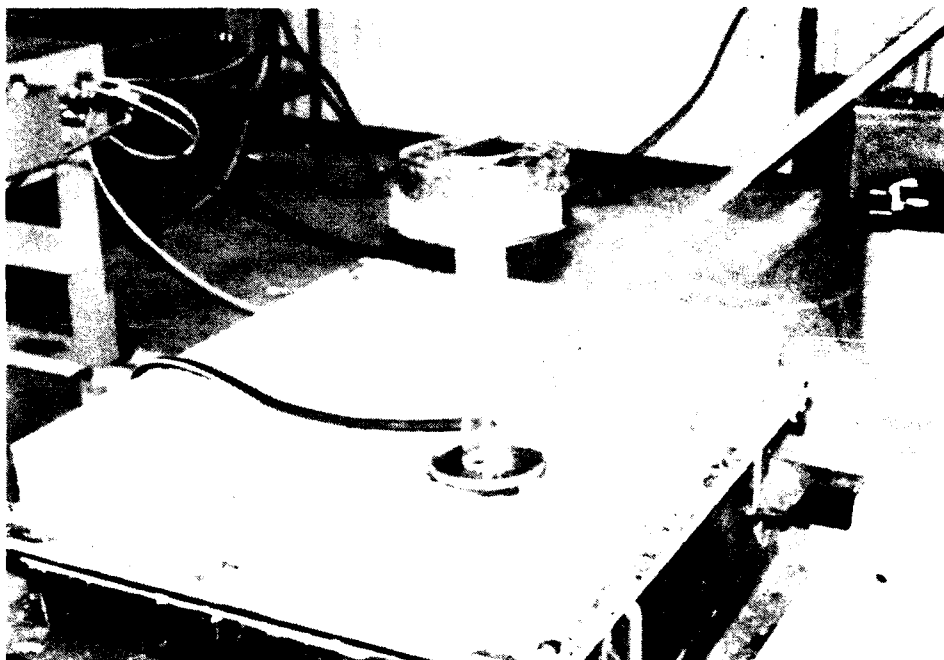


Photo 21. Permeability test

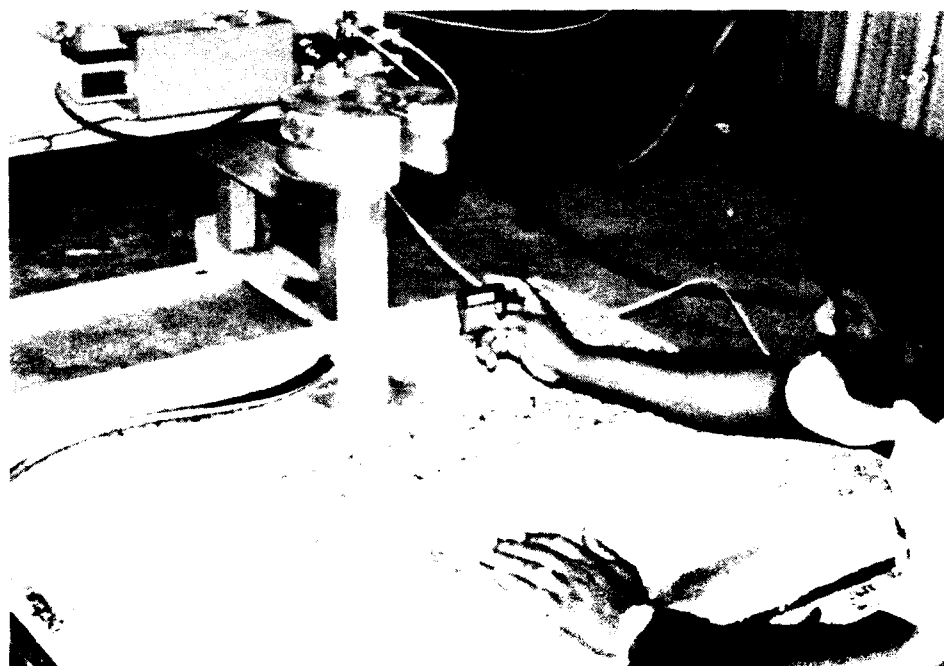


Photo 22. Timing the water fall

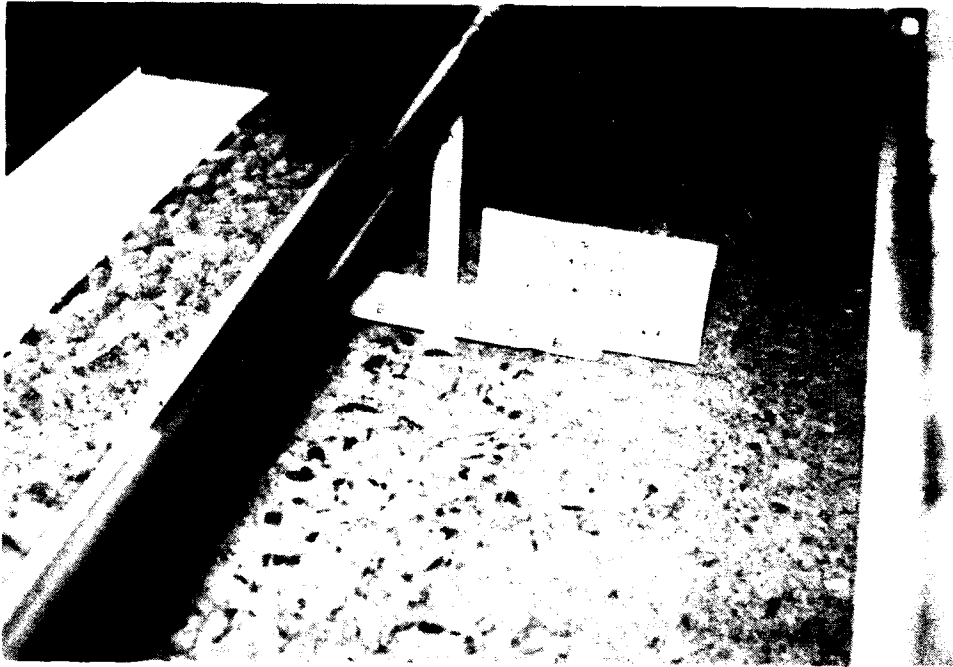


Photo 23. Standard crushed gradation during testing



Photo 24. Standard crushed gradation during testing

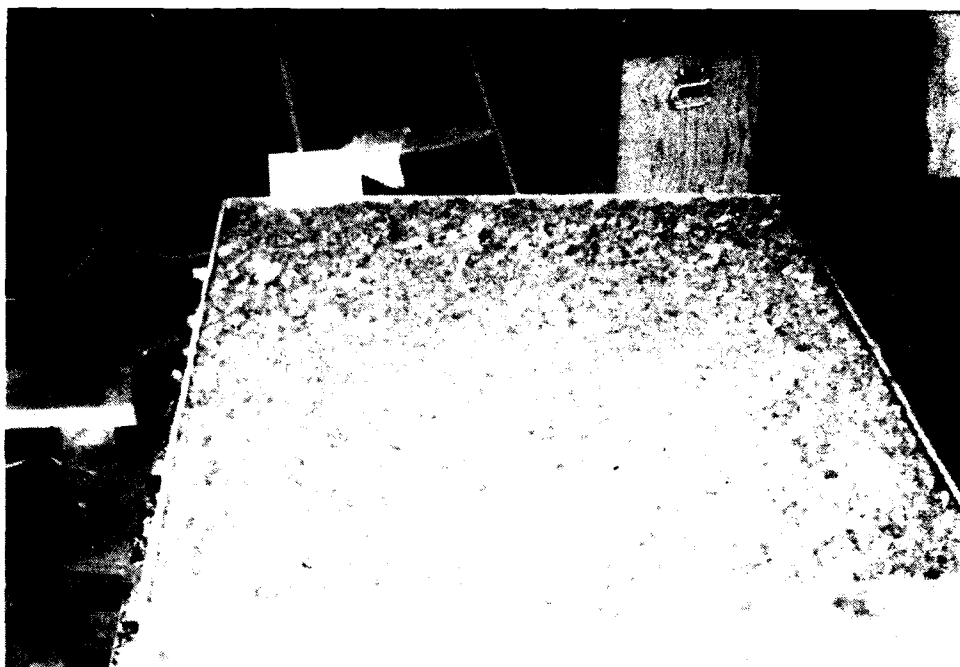


Photo 25. CS-I crushed gradation before traffic

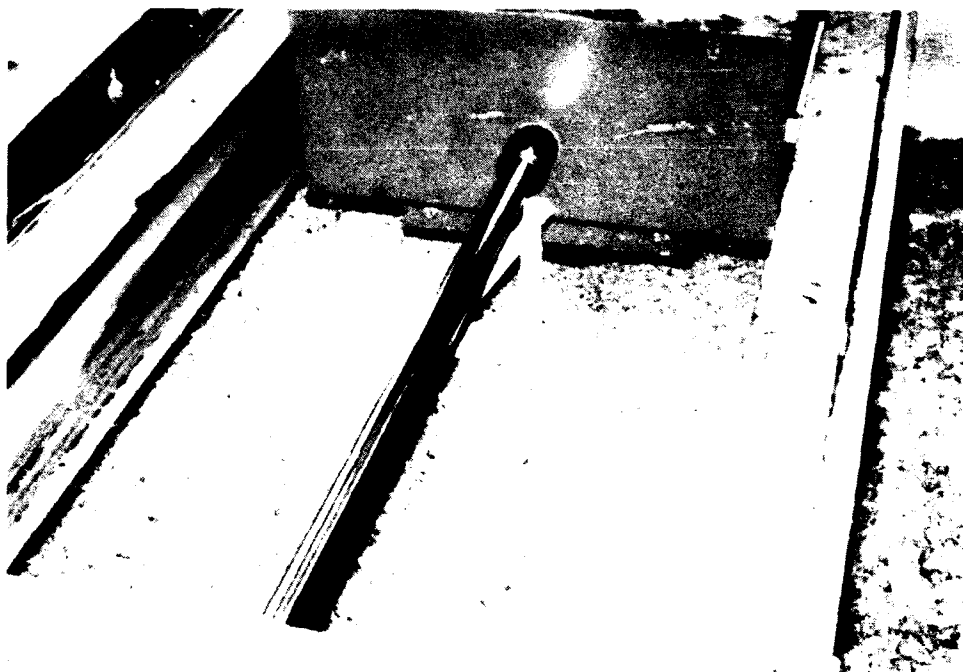


Photo 26. CS-I crushed gradation during testing

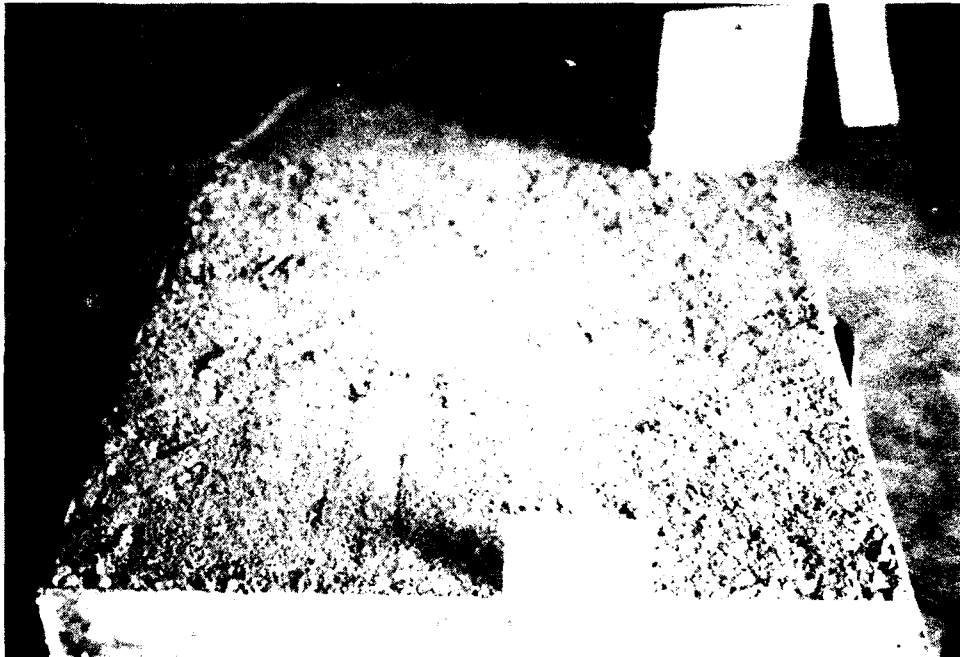


Photo 27. CS-II crushed gradation before traffic

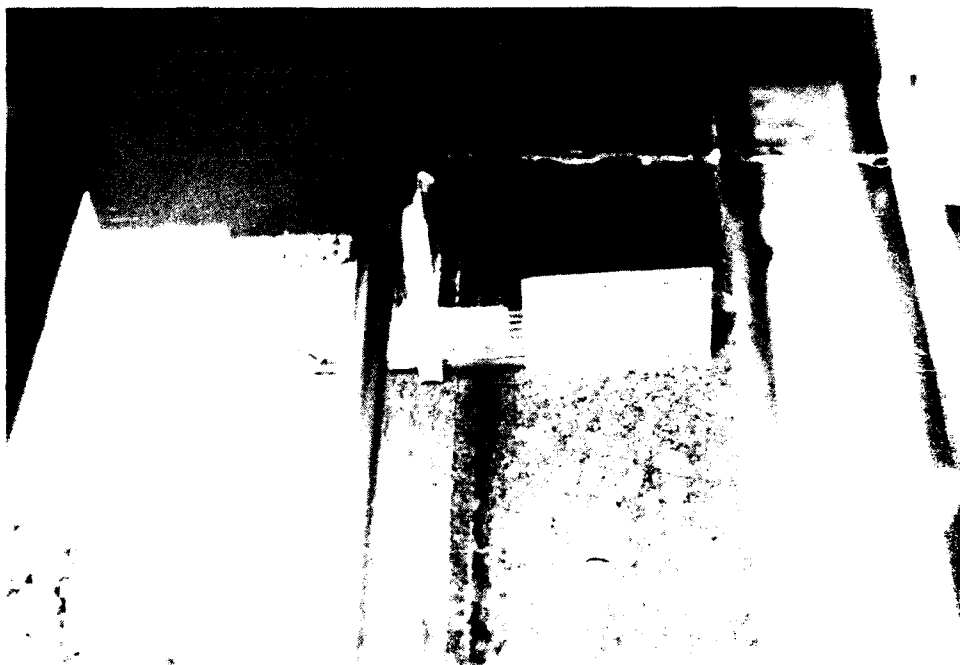


Photo 28. CS-II crushed gradation during testing

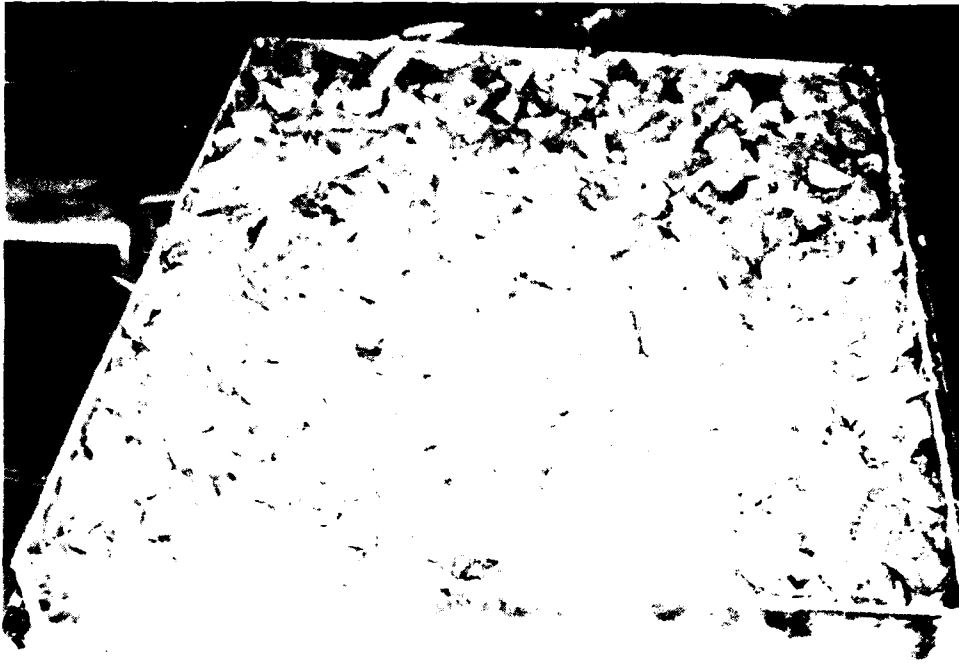


Photo 29. CS-III crushed gradation before traffic

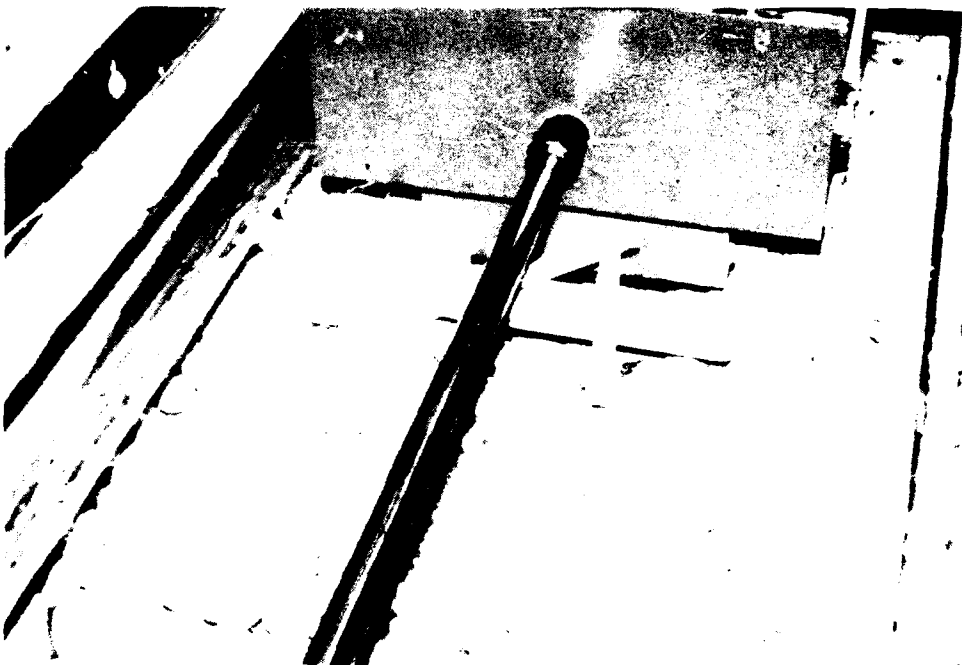


Photo 30. CS-III crushed gradation during testing



Photo 31. CS-IV crushed gradation before traffic

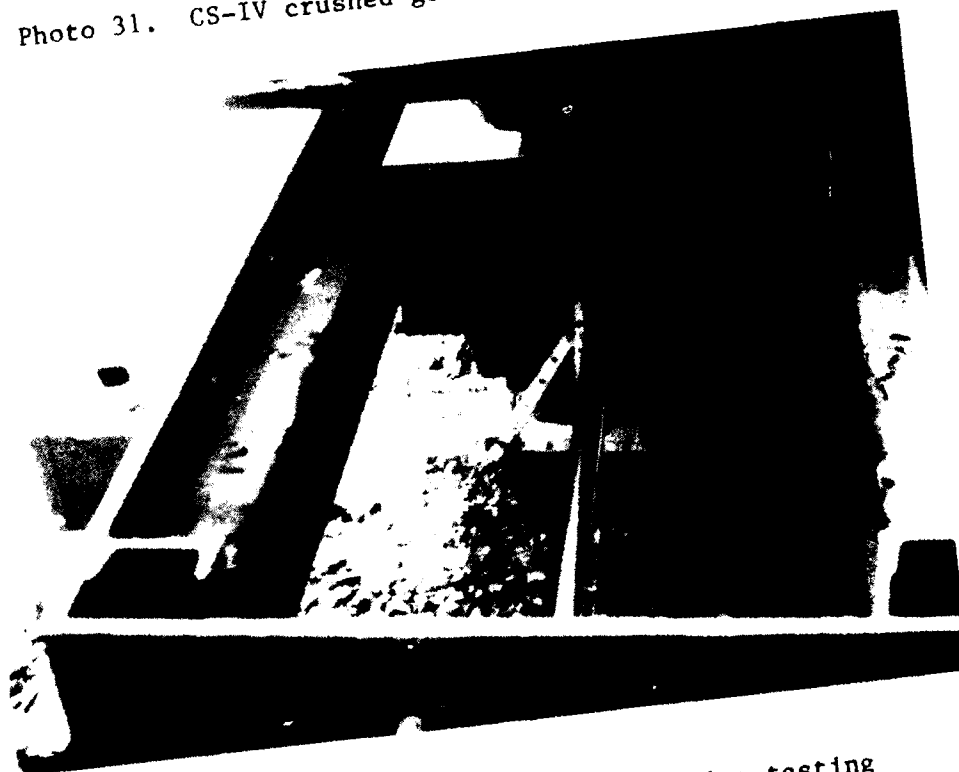


Photo 32. CS-IV crushed gradation during testing



Photo 33. CS-V crushed gradation before traffic

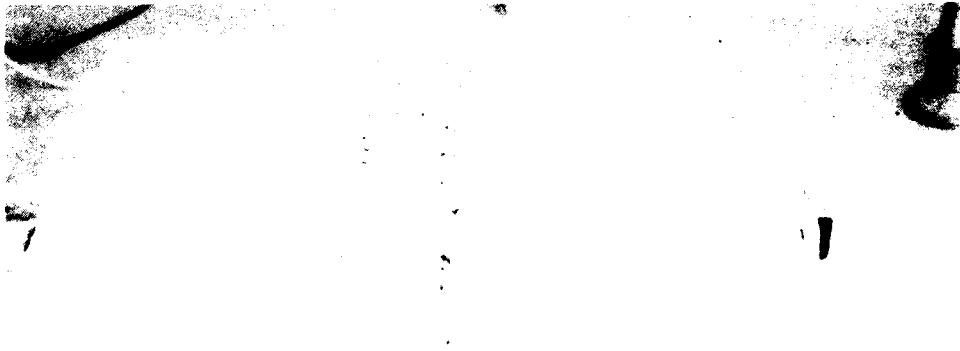


Photo 34. CS-V crushed gradation during testing

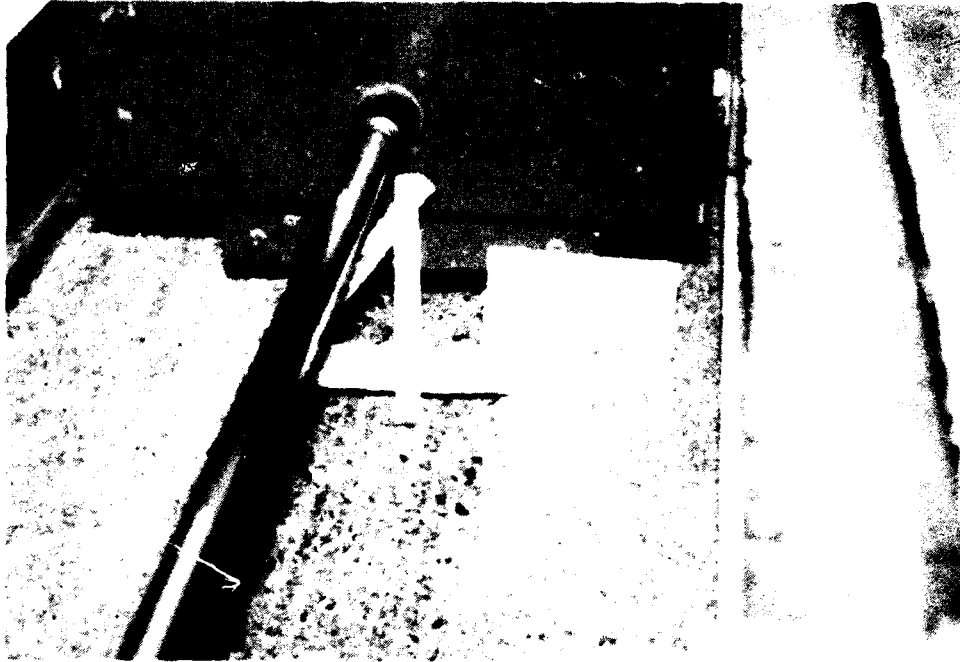


Photo 35. CS-VI crushed gradation before traffic

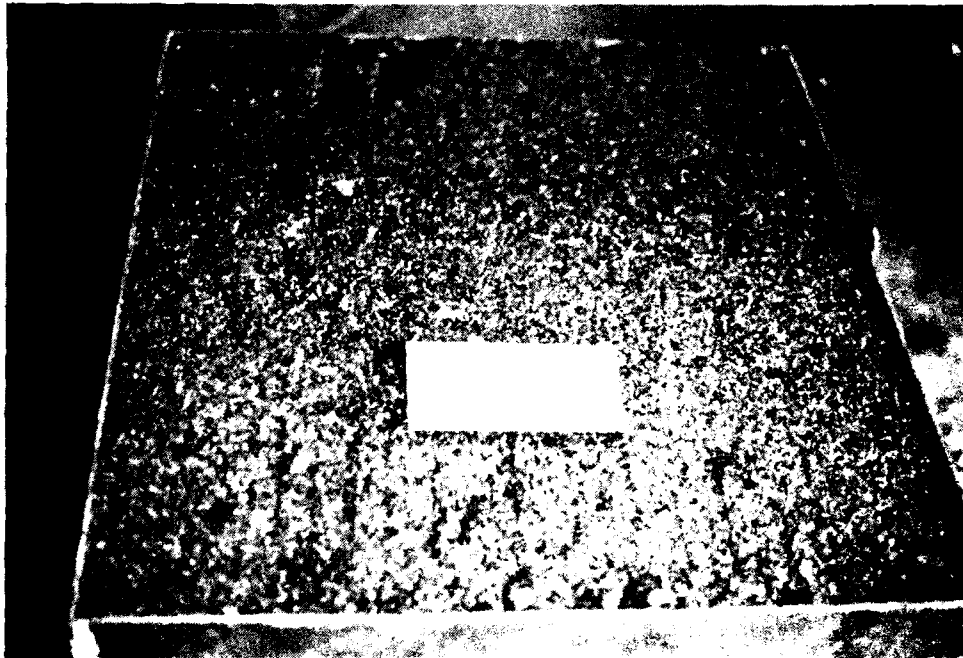


Photo 36. CS-V rounded gradation before traffic

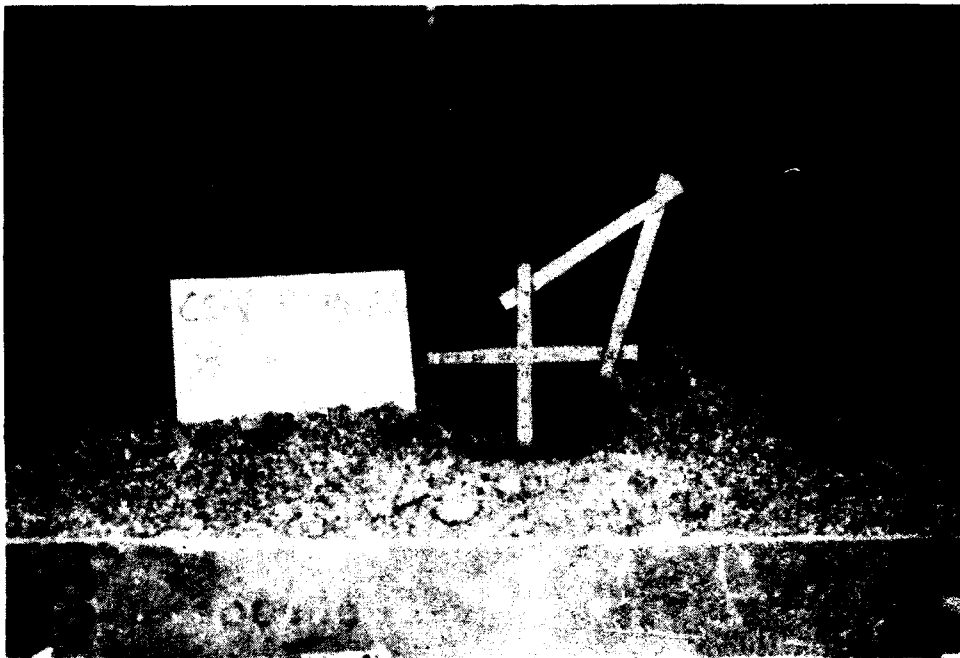


Photo 37. CS-V rounded gradation after 8 passes

Waterways Experiment Station Cataloging-In-Publication Data

Gonzalez, Carlos R.

Stability of open-graded bases under wheel loads using a model testing approach / by Carlos R. Gonzalez ; prepared for Department of the Army, U.S. Army Corps of Engineers.

44 p. : ill. ; 28 cm. -- (Miscellaneous paper ; GL-92-11)

1. Roads -- Base courses -- Models. 2. Pavements -- Live loads -- Testing. 3. Engineering models. 4. Stone, Crushed -- Testing.
I. Title. II. United States. Army. Corps of Engineers. III. U.S. Army Engineer Waterways Experiment Station. IV. Series: Miscellaneous paper (U.S. Army Engineer Waterways Experiment Station) ; GL-92-11.

TA7 W34m no.GL-92-11